



**US Army Corps
of Engineers®**
Engineer Research and
Development Center

Snow Harvesting: A Potential Water Source for Afghanistan

Kyle J. Thompson, Karen S. Henry, Janet P. Hardy, and
Adam M. Chalmers

August 2009

Snow Harvesting: A Potential Water Source for Afghanistan

Kyle J. Thompson and Adam M. Chalmers

*Department of Civil and Mechanical Engineering
U.S. Military Academy
West Point, NY 10996-1905*

Karen S. Henry

*Department of Civil and Environmental Engineering
U.S. Air Force Academy
USAF Academy, CO 80840-6232*

Janet P. Hardy

*Cold Regions Research and Engineering Laboratory
U.S. Army Engineer Research and Development Center
72 Lyme Road
Hanover, NH 03755-1290*

Approved for public release; distribution is unlimited.

Abstract: Afghanistan has limited water sources, and the possibility of using a snow fence to concentrate, or “collect,” snow to provide a supplemental source of water, upon melting, in the Bamian region was examined. In Afghan villages, women and/or children often fetch water for their families. Improving water usage efficiency could improve agricultural productivity, reduce the number of trips to the nearest water source, and provide healthier daily nutritional intake. Snow fences are currently used to manage the distribution of snow for the purposes of supplementing water supply. Hence, the researchers determined the average amount of water required for sheep and cows per village using demographic data. Then, they compared this volume of water to the equivalent volume of snow that can be captured with a snow fence, based on current knowledge of snow fence function. Analysis of topographic and meteorological data indicated that many areas in Bamian are favorable for collection of snow for eventual water harvesting. A 100-m-wide “solid” fencing (e.g., rocks), approximately 3 m high, was estimated to be able to provide 16%–17% of a “typical” Bamian village’s livestock water, whereas a highly efficient, 50% porous fence could provide approximately 47% of the livestock water. The research team’s recommendation was to further assess implementation of the snow fence water-collection method as a supplementary water source in rural areas of Afghanistan that receive annual snowfall.

DISCLAIMER: The contents of this report are not to be used for advertising, publication, or promotional purposes. Citation of trade names does not constitute an official endorsement or approval of the use of such commercial products. All product names and trademarks cited are the property of their respective owners. The findings of this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

DESTROY THIS REPORT WHEN NO LONGER NEEDED. DO NOT RETURN IT TO THE ORIGINATOR.

Contents

Figures and Tables	iv
Preface	v
1 Introduction.....	1
Project overview	1
Afghanistan geography and water.....	1
Background–Afghanistan	2
Background–snow fences	2
Scope of work	3
2 Snow Fence Method Assessment in Bamian Province	4
3 Snow Harvesting.....	7
Overview of snow fence function.....	7
Snow fence design and emplacement.....	8
Snow conditions in Bamian for concentration of water via snow fence.....	9
Snow fence materials.....	17
4 Socioeconomic Considerations.....	19
5 Conclusions and Recommendations	20
Conclusions	20
Recommendations	20
References.....	21
Report Documentation Page	

Figures and Tables

Figures

Figure 1. Maps of Afghanistan.....	5
Figure 2. Snow drift accumulating on downwind side of fence.....	7
Figure 3. Fetch is the maximum distance between the source of snow drift and the snow fence.....	9
Figure 4. Volume of water equivalent estimated to be transported per meter-width across the wind direction for SWE of 0.1 m, as a function of fetch distance.....	10
Figure 5. Volume of snow (water) storage created per meter-width of snow fence with 50% porosity, as a function of fence height.....	11
Figure 6. Volume of water equivalent estimated to be available for capture across the wind direction for a SWE of 0.1 m as a function of fetch distance for various distances perpendicular to the wind.....	12
Figure 7. Volume of snow (water) storage created for a snow fence with 50% porosity, as a function of fence height for 40-m and 100-m-wide fences.....	13
Figure 8. Northeast corner of the Bamian province depicting areas of 10-deg slope or less.....	14
Figure 9. Northeast corner of the Bamian province depicting areas of rangeland where snow relocation can occur.....	15
Figure 10. Northeast corner of the Bamian province depicting areas of optimal fetch where both optimal slope and rangeland occur simultaneously.....	16
Figure 11. Expanded map of Bamian depicting areas of optimal fetch for snow fence.....	17
Figure 12. Wind rose diagram of Bamian shows wind coming predominantly from the east.....	18

Preface

This report was prepared by Kyle J. Thompson and Adam M. Chalmers of the Department of Civil and Mechanical Engineering of the U.S. Military Academy at West Point; Dr. Karen S. Henry of the Department of Civil and Environmental Engineering at the U.S. Air Force Academy, Colorado; and Janet P. Hardy of the Terrestrial and Cryospheric Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, NH.

The work reported herein was conducted under the U.S. Army Corps of Engineers' Military Engineering (AT40) program. The authors gratefully acknowledge the sponsorship and support of the ERDC-U.S. Military Academy Memorandum of Agreement. In particular, the encouragement of Dr. Paul Mlakar of the ERDC Geotechnical and Structures Laboratory is greatly appreciated. The report was prepared under the general supervision of Dr. Justin B. Berman, Chief, Research and Engineering Division, and Dr. Robert E. Davis, Director, CRREL.

The Commander and Executive Director of ERDC is COL Gary E. Johnston. The Director is Dr. James R. Houston.

1 Introduction

Project overview

Afghanistan currently has limited water sources and water storage capabilities, with many regions suffering recurring drought. A widespread drought occurred from 1997 to 2002, causing a significant decrease in agricultural production and water consumption (International Center for Agricultural Research in the Dry Area 2002). Opium-producing poppies in Afghanistan are drought resistant compared with most crops. Increasing water supply for irrigation or other purposes may help improve the ability to grow crops such as wheat.

This project examined one potential method to supplement water supply—and possibly to help mitigate drought—that would be applicable in regions receiving seasonal snow. The method uses a snow fence to concentrate, or “collect,” blowing snow. Upon melting, the snowmelt provides a water “harvest.”

Afghanistan geography and water

Afghanistan has three major geographical regions. The northeastern region consists of mountainous terrain with average elevations over 3000 m. The north-central region is a fertile valley between the Hindu Kush mountain range and the Amu Darya River. The southwest is mostly desert. Lifestyles differ greatly among these regions, partially due to significant differences in geography and access to water.

In the past 50 years, Afghanistan has suffered war and regime changes. This political instability has exacerbated the already struggling economy, which is largely dependent on farming. Irrigation constitutes about 85% of the watering methods used in Afghanistan (International Center for Agricultural Research in the Dry Area 2002). Rural farms require approximately 800 to 1000 m³ of water per person annually in order for crops to yield adequate nutritional value (UN-Water 2007).

At least 80% of Afghanistan’s water is supplied by snowmelt from the Hindu Kush mountain range (International Center for Agricultural Research in the Dry Area 2002). The snowmelt runoff from the Hindu Kush “tends to be irregular and low” (Masood and Mahwash 2008). Because of Afghanistan’s dependence on snowmelt as a water source, an abbreviated or mild winter can result in drought,

especially for those living in rural areas. On the other hand, an exceptionally high amount of snow in the winter combined with rapid warming in the spring often leads to flooding (Canfield 1973).

Background–Afghanistan

According to the United Nations, an individual requires a minimum of 20 liters of water per day (UN-Water 2007). Areas affected by drought and/or war often fail to meet this requirement. In the case of Afghanistan, much of its infrastructure was destroyed during the war with Russia in the 1980s, including many irrigation canals (International Center for Agricultural Research in the Dry Area 2002). Later, under Taliban rule from 1992 to 2001, reconstruction was nearly nonexistent as the country's economic situation remained poor (*Encyclopedia Britannica* 2008). Additionally, the 1997–2002 drought made water acquisition for Afghanistan a top priority.

In many Afghan villages, women and/or children travel between the village and the nearest water source to fetch water for their families. Depending on the severity of the water need, multiple trips are often required, taking considerable time. For example, in the village of Qadam Joy, on the outskirts of Sarepul, in Northern Afghanistan, women and children travel back and forth for the entire day in order to meet their village's water needs (Gill 2008). Women comprise over 70% of the Afghan agricultural labor force; despite their involvement in water collection and agriculture, women in poor households especially suffer from malnutrition during periods of food shortages (Kelly 2003). This occurs, in part, because of their inferior status in the paternalistic society (Kelly 2003). According to the Asian Development Bank, improving water usage efficiency would at least double agricultural productivity (Kelly 2003). Not only will this likely reduce the number of trips women make to the nearest water source, but the women will also likely benefit from a healthier daily nutritional intake.

Background–snow fences

Snow fences are, and have been, used to manage the distribution of snow for the purposes of supplementing water supply. The Canadian Government provides guidance on the use of snow fences to concentrate water into “dugouts” on the Canadian Prairies (http://www.agr.gc.ca/pfra/drought/info/snowfence_e.htm), and McFadden and Collins (1978) used snow fences to supplement the water supply at Point Hope, Alaska (McFadden and Collins 1978). Jairell and Schmidt (1992) described a method of locating a snow fence, a pit, and a berm perpendicular to the prevailing

wind direction and downwind, respectively, in a parallel configuration for the purpose of capturing blowing snow in the winter and storing it for livestock use when the snow melts. They included estimates of snow available for capture as well as snow storage capacity created by the snow fence in order to properly size the pit for water storage. Sturges (1992) described an experiment in which a 3.8-m-high snow fence, 800 m long, was constructed on a rangeland watershed, parallel to an incised channel (38 m upwind of the channel), in order to study its influence on water production. Two adjacent watersheds were used in the study, and one watershed was used as a control. In addition, several years of snowmelt runoff data (from the “snow fence-treated” watershed prior to installation of the snow fence) were available. Results from a 5-year study indicated that the snowmelt runoff increased by 129%, and that an average of 39% of the channel snow was converted into streamflow. Jairell and Schmidt, as well as Sturges, utilized and described snow management techniques developed by Tabler (1991; 2003), an engineer whose work was also used in the work described in this report.

Scope of work

The scope of this project was to evaluate the possibility of using a snow fence to capture drifting snow and preserve it for water harvesting, in regions where seasonal snow occurs and additional water during summer months would be beneficial. Currently in Afghanistan, the most common means for water extraction and storage are wells and irrigation canals (International Center for Agricultural Research in the Dry Area 2002). Snow fences may provide a low-technology, stable, and cost-efficient supplement to the current water extraction and storage methods. To make this assessment, the research team developed a “case study village” based on demographic information in the Bamian (also spelled Bamiyan) region of Afghanistan.

Since the snow fence water-collection method will probably be less sanitary than water drawn from wells, its usage is likely to be best suited to support livestock. The team determined the average amount of water required for sheep and cows per village and then converted it into the corresponding required volume of snow. Then, this volume of snow was compared with the volume of snow that can be captured via the snow fence method. It was found that the snow fence water-collection method can account for a substantial portion of the sheep and cows’ annual water requirements. However, the success of projects to increase water supply using snow fences depends not only upon the ability to capture the snow but also the effect that introducing a new water source has upon the socioeconomic dynamics of any population center in which the method is implemented.

2 Snow Fence Method Assessment in Bamian Province

Detailed geographic and demographic information about Afghanistan is hard to obtain. However, there is strong evidence that the Bamian province is an area in which at least some villages require more water. Bamian is arid and, like most of Afghanistan, experienced a severe drought from 1997 to 2002 (Figure 1) (International Center for Agricultural Research in the Dry Area 2002). In a survey taken of five Afghan provinces (Herat, Helmand, Ghazni, Balkh, and Baghlan) (note that Balkh and Baghlan border Bamian and share similar geographic features), the drought reportedly caused a 47% decrease in crop production (International Center for Agricultural Research in the Dry Area 2002). Minor drought tends to occur every 4 to 5 years, with a major drought occurring every 30 years (International Center for Agricultural Research in the Dry Area 2002).

The waters of Bamian flow into the Kunduz-Oxuz river basin (Masood and Mahwash 2008). However, Bamian itself is isolated from the Kunduz-Oxuz river basin because of the rugged highlands that surround it. Source streams at elevations of about 2600 m flow into the Kunduz river from the surrounding gorges of the Koh-i-Baba (the Koh-i-Baba mountain range extends from the Hindu Kush proper) (Yule 1890). Drought does not affect the discharge of main rivers, such as the Kunduz, nearly as much as it affects the tributary streams of the main river (Alim and Shobair 2002). Tributary streams with catchment basins below elevations of 3000 m experience acute shortages of water, and those below elevations of 2000 m are “seriously affected by the drought” (Alim and Shobair 2002). Because of the low elevations of the Kunduz River’s source streams, many of its tributary streams “flow only seasonally, drying to a trickle or becoming totally dry during part of the year” (Illinois Institute of Technology 2008).

The central part of the Bamian enjoys the most fertile ground, with long growing seasons (Masood and Mahwash 2008). However, in the surrounding highland areas, the crop yield is less abundant due to the increased altitude, which results in a shorter growing season (Masood and Mahwash 2008). Certain areas of the highlands lack a dependable water source, while others have too much water (Masood and Mahwash 2008). Hence, it was hypothesized that the snow fence

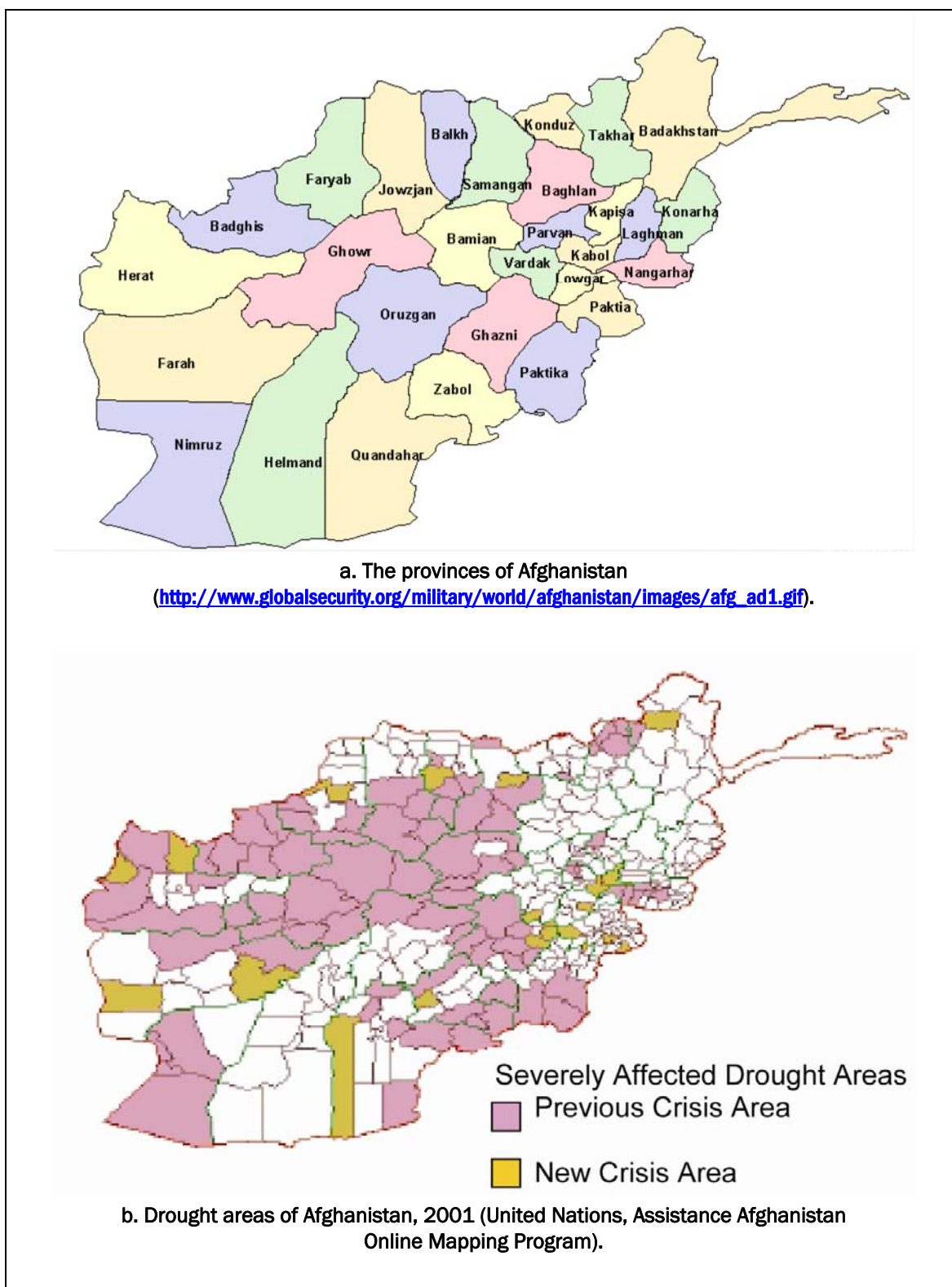


Figure 1. Maps of Afghanistan.

collection method offers promise for villages within the highland areas that lack a dependable water source.

The snow fence collection method requires the presence of seasonal snow. At least some villages in Bamian meet this requirement, and permanent snow pack exists at elevations over 3655 m (Palka 2001). Bamian receives peak snowfall from February to March, with snowfall averages during the month of February reaching about 1 to 1.5 m in depth (ERDC/CRREL Remote Snow Assessment Team 2008; Agromet Network 2007). Assuming a snow density of about 25% (meaning 0.25 times the density of water), this snow contains the equivalent of about 0.25 m of water per meter of snow. This represents a conservative estimate for Bamian where snow densities are estimated to reach up to 40%.¹ Snow densities in snow drifts can reach up to 45% as more snow accumulates onto the snow drift and settles (Jairell and Schmidt 1992).

In central Bamian, 67,305 people live in 167 villages (Livelihoods Connect 2008). The average family size is 4.8 people, resulting in an estimate of 13,925 families living in the 167 villages, or 83 families per village. Each family has about two cows and ten sheep, resulting in 167 cows and 834 sheep for an “average” village. Sheep in areas with poor water quality require about 3.6 m³ of water annually, and dairy cows require about 22 m³ of water annually (New South Wales Department of Water and Energy 2008). Therefore, the estimated amount of water needed to sustain an average village’s sheep and cows is 6676 m³ annually. In the same survey taken of the five provinces, responses showed that anywhere from 42% to 82% of the villagers shared their drinking water with livestock (International Center for Agricultural Research in the Dry Area 2002). The snow fence water-collection method could provide an alternative water source for animal consumption, allowing the Afghan people to drink the more sanitary well water.

¹ S. F. Daly, pers. comm. 2008. Research Hydraulic Engineer, U.S. Army Engineer Cold Regions Research and Engineering Laboratory, Hanover, NH.

3 Snow Harvesting

Overview of snow fence function

When wind passes through a porous snow fence, its velocity slows, causing heavy snow particles to fall and accumulate on the downwind side of the snow fence (Tabler 1991). Some accumulation occurs on the upwind side of the snow fence, but the majority falls on the downwind side (Figure 2). The length of the downwind drift can reach distances up to 35 times the height of the fence (Tabler 1991).



Figure 2. Snow drift accumulating on downwind side of fence (from <http://www.wrds.uwyo.edu>).

As discussed above, snow captured by a snow fence can also be harvested and possibly stored for later use. Some losses of snow water volume will occur between the time of capture and the time of usage due to evaporation (about 33%) and blowing and drifting (also referred to as overland conveyance) (about 33%), leaving the remaining one-third of snow water volume available as a water source.¹ To fully satisfy the estimated annual requirement of 6676 m³ of water for the cows and sheep of an average Bamian village, the snow fence collection method would have to concentrate 20,029 m³ of water.

¹ R. D. Tabler, pers. commun. 2008. Research Hydraulic Engineer, Tabler & Associates, Niwot, CO.

Snow fence design and emplacement

Snow fences for collecting water should be sized based on annual average maximum snow water equivalent (defined below), fetch (description below), and the desired volume of snow accumulation downwind of the snow fence. Any one of these factors can limit the amount of water captured and stored by a snow fence. In addition, there are practical limits on the snow fence dimensions. For example, snow fences are typically no taller than 4 m.

The snow water equivalent (SWE) is a measure of the amount of water contained within the snow. It is the “depth of water that would theoretically result if you melted the entire snowpack instantaneously” (U.S. Department of Agriculture (USDA) 2008). SWE is a function of the snow depth and density (USDA 2008). As the snow settles over time, it can reach densities between 40% and 50% that of water (USDA 2008). Thus, in Bamian, where average depths can reach 1 m in depth, a SWE of 0.25 m (based on an assumed density of 25% and a snow depth of 1 m) used for volume predictions represents a conservative estimate.¹

Fetch is the distance upwind of the snow fence from where the snow is relocated that is free of obstacles (Figure 3). The fetch must be relatively free from tall vegetation, as trees 3 to 6 m tall promote snow deposition and prevent drifting (Tabler 1991). When trying to capture a certain amount of snow, the slope, vegetation, and length of the fetch must be taken into account. The ideal slope of a fetch is approximately 10 to 12 deg downhill (Tabler 2003). This corresponds to the equilibrium slope of snow drifts when separation of airflow begins to occur, and the snow deposits uniformly along the ground in the shape of its equilibrium profile (Tabler 2003). A relatively flat surface upwind of the fence also promotes snow deposition downwind of the snow fence. Curved surfaces and terrain cuts upwind create eddies that will cause the snow to deposit before reaching the snow fence (Tabler 2003).

Given the appropriate slope and vegetation cover, longer fetch yields greater snow drift volumes. Fetch begins at an upwind region and ends at the snow fence (Figure 3). “The upwind end of the fetch is any boundary across which there is no snow transport, such as forest margins, deep gullies or stream channels, rows of trees, and shorelines of unfrozen bodies of water” (Tabler 2003). Snow is

¹ S. F. Daly, pers. comm. 2008. Research Hydraulic Engineer, U.S. Army Engineer Cold Regions Research and Engineering Laboratory, Hanover, NH.

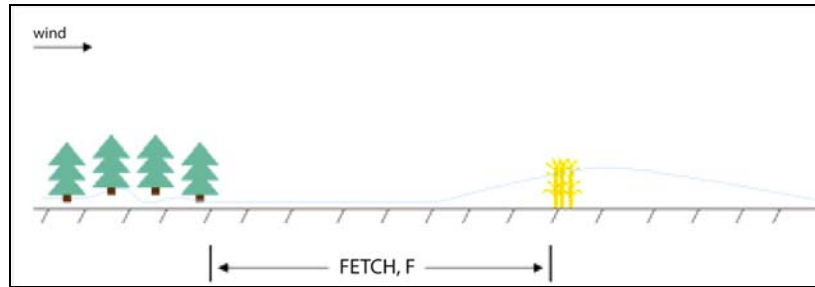


Figure 3. Fetch is the maximum distance between the source of snow drift and the snow fence. In this example, rows of corn left standing serve as the snow fence (from <http://climate.umn.edu/>).

relocated from the upwind region of the fetch, and the majority accumulates on the downwind side of the snow fence.

Snow conditions in Bamian for concentration of water via snow fence

As described below, sufficient SWE and fetch apparently occur throughout many areas of the Bamian province to provide a source of water. Thus, snow harvesting with the use of snow fences is worthy of further consideration. Tabler (2003) published a monograph on the design of snow fences to control blowing and drifting snow, and the following analysis is based on his work. The two factors considered are quantity of snow available to be captured by a snow fence (i.e., snow that is usually relocated due to wind) and the storage capacity of the snow fence.

The snow available for relocation typically ranges from 20% to 70% of the snow that falls to the ground. Hence, if a SWE of 0.25 m is assumed (related to an assumed 1 m of snow depth), it is reasonable to assume that a SWE of 0.1 m is available to be captured by a snow fence. Tabler (2003) provided the following equation to estimate the total seasonal transport of snow (kg/m-width perpendicular to the wind direction), Q_t , that also accounts for evaporative losses during wind transport:

$$Q_t = 500 TSWE_r \left(1 - 0.14 \frac{F}{T} \right) \quad (1)$$

where:

T = maximum transport distance, m (estimated to be 3000 m in most cases, and a reasonable default value when specific information is lacking)

SWE_r = snow water equivalent that is relocated seasonally

F = fetch.

Using the “default” maximum transport distance, T , of 3000 m, an estimated SWE_r of 0.1 m, and an assumed fetch of 1500 m, the estimated snow available for transport under these conditions is 94,000 kg, or 94 m³ of water, per meter-width across the wind. Note that this equation is based on the estimated amount of snow that is transported from the ground surface to a height of 5 m. However, most snow transport occurs within 1 m of the surface, with less than 10% being transported above 1.5 m when the wind is blowing 35 km/h (Tabler 2003).

Figure 4 shows the estimated snow water equivalent transported by wind and, hence, available for capture per meter-width across the wind direction for a SWE of 0.1 m, as a function of fetch distance for an assumed transport distance of 3000 m.

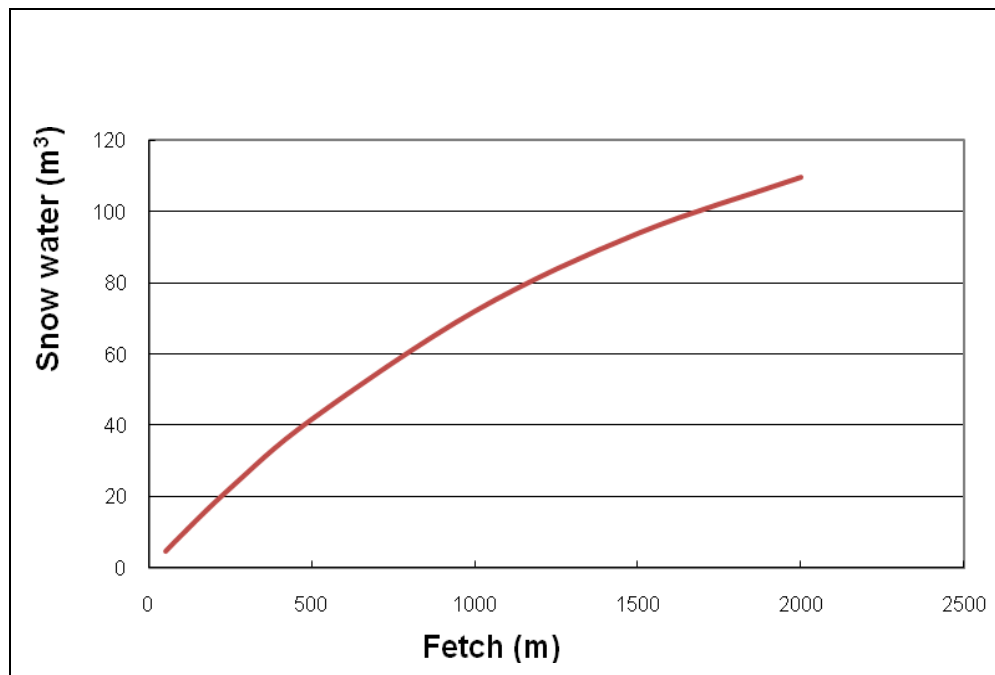


Figure 4. Volume of water equivalent estimated to be transported (i.e., available for capture) per meter-width across the wind direction for SWE of 0.1 m, as a function of fetch distance. It is based on an assumed transport distance of 3000 m.

Since a short, 10-m width across the wind contains 4.7% ($940 \text{ m}^3/20,027 \text{ m}^3$) of the estimated water requirement in relocated snow for the case study village's livestock, study of the storage capabilities of a snow fence is warranted.

The amount of snow water storage provided by a snow fence is a function of its porosity and height. The most efficient snow fences are 50% porous, with horizontal slats, and the least efficient are nonporous fences. (In the case of nonporous fences, the drifts accumulate upwind of the fence until they reach the fence height.) Based on the assumption that the fence is 50% porous, the snow storage capacity of the fence, Q_c , in metric tons per meter-width of fence is given as (Tabler 2003):

$$Q_c = 8.5H^{2.2} \quad (2)$$

where H is the fence height (m).

One metric ton of snow (i.e., water) is equal to 1 m^3 of water. Hence, with a 50% porous fence, a height of 3 m is required to capture and store most, if not all, of the estimated 94 m^3 of water available. Figure 5 shows the volume of snow water storage per meter-width of snow fence created by a 50% porous snow fence as a function of height.

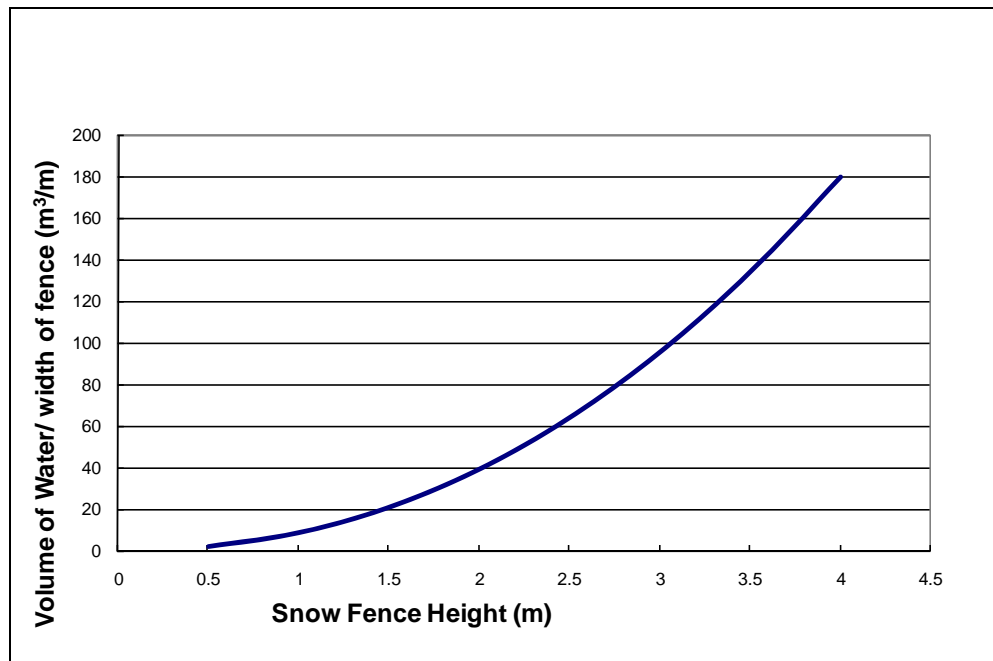


Figure 5. Volume of snow (water) storage created per meter-width of snow fence with 50% porosity, as a function of fence height.

Figure 6 shows estimates of the volume of water available for capture as snow across the wind direction (for a SWE of 0.1 m) as a function of fetch distance for various distances perpendicular to the wind. These perpendicular distances are taken as first approximations of snow fence widths.

Figure 7 shows the volume of snow storage created by snow fences of various heights for snow fence widths of 40 m and 100 m.

The research team performed an assessment of fetch in Bamian using satellite imagery and determined that fetches of 1.5 km do occur in numerous locations within Bamian. Using Equation 1, this fetch—with a SWE of 0.1 m and a 100-m-wide fence—would provide approximately 9400 m³, or 47% of the case study village's livestock water (Figure 6). Again, this is based on the assumption of a 50% porous snow fence at least 3 m high.

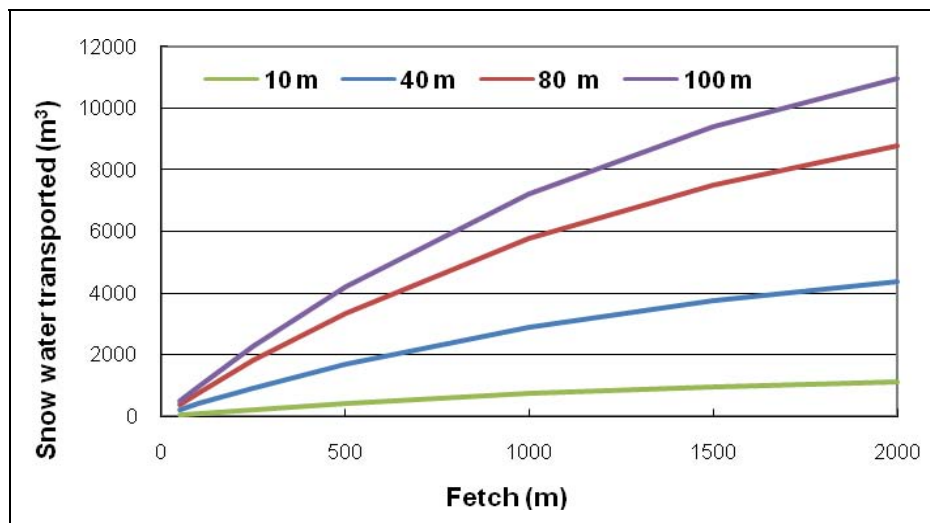


Figure 6. Volume of water equivalent estimated to be available for capture across the wind direction for SWE of 0.1 m as a function of fetch distance for various distances perpendicular to the wind (snow fence widths); based on assumed transport distance of 3000 m.

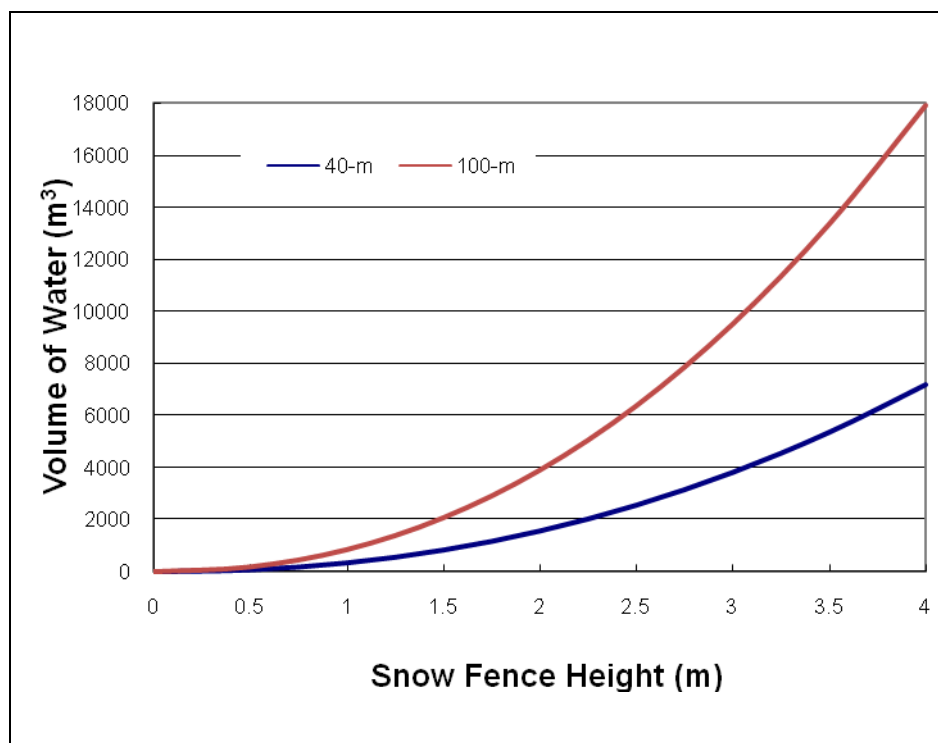


Figure 7. Volume of snow (water) storage created for a snow fence with 50% porosity, as a function of fence height for 40-m and 100-m-wide fences.

In Figure 8, areas of 10-deg slope or less are highlighted. Figure 9 shows rangeland areas that provide suitable land cover for establishing fetch. (Rangeland consists of low-lying shrubs and grasses.)

Figures 10 and 11 show areas where the ideal slope and rangeland conditions intersect. A number of these areas occur in river basins, which are potentially helpful in later water storage.

When positioning the snow fence, the most important consideration is wind direction. According to Tabler (2003), wind direction can be determined by performing the following tasks:

- Analyze meteorological data from a representative weather station;
- Determine direction of the drift features in the field;
- Determine direction of the drift features using aerial photographs;
- Note the orientation of wind-sculpted vegetation, such as flagged or bent trees, or snow-caused abrasion on wooden poles or posts (Livelihoods Connect).

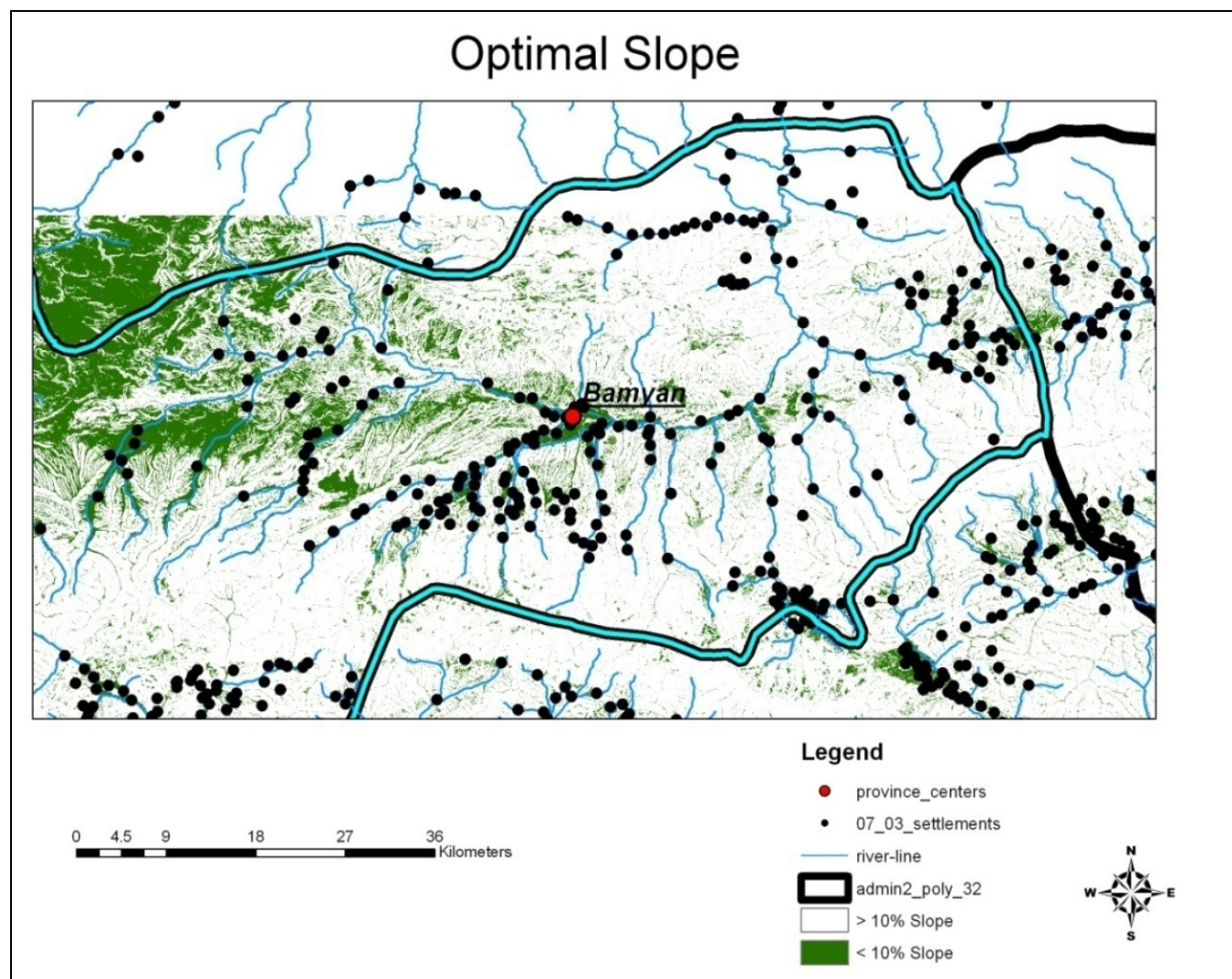


Figure 8. Northeast corner of the Bamian province depicting areas of 10-deg slope or less (GIS analysis, 2008, Department of Geography and Environmental Engineering, U.S. Military Academy).

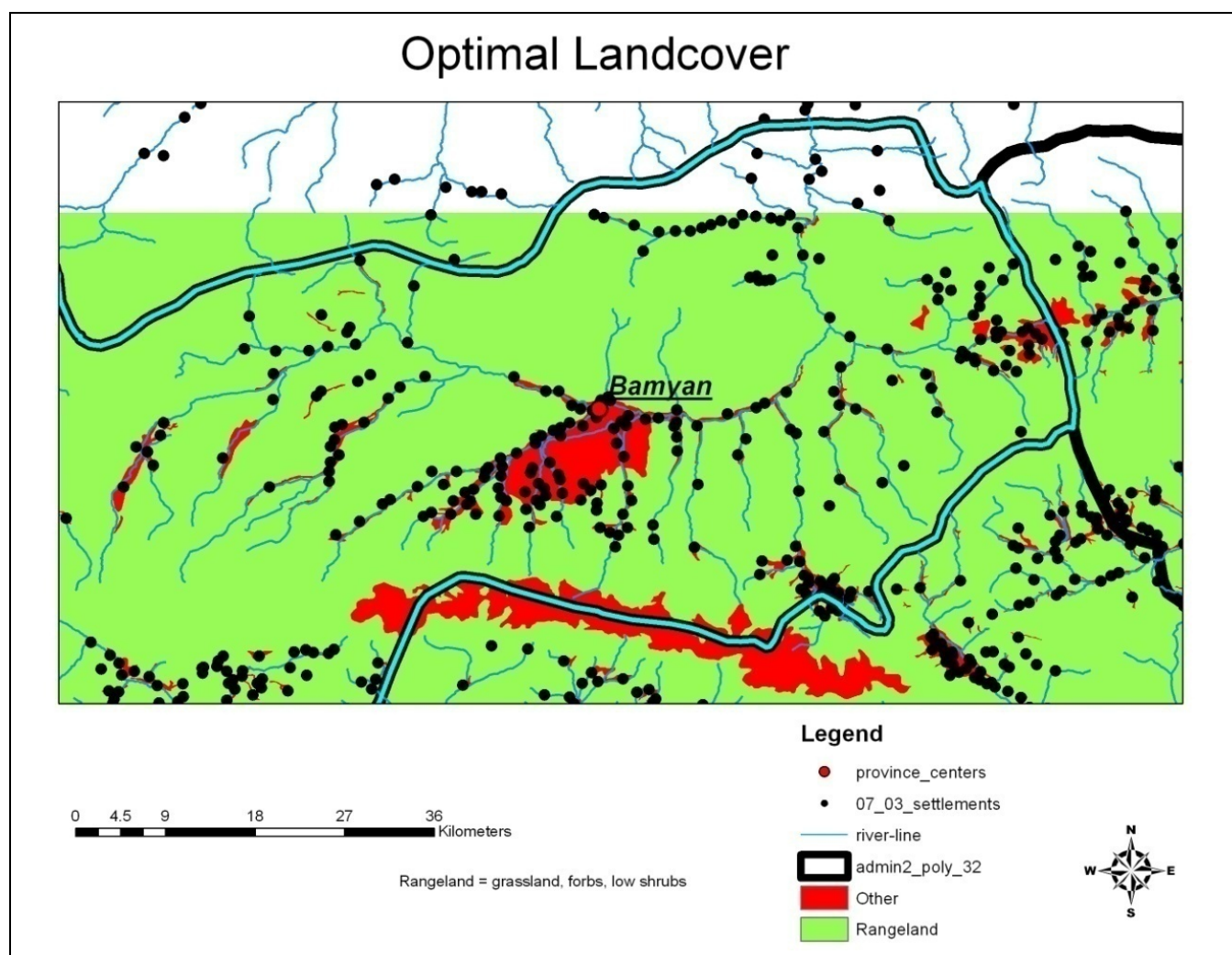


Figure 9. Northeast corner of the Bamian province depicting areas of rangeland where snow relocation can occur. Vegetation of rangeland consists of grasslands and low-lying shrubs (GIS analysis, 2008, Department of Geography and Environmental Engineering, U.S. Military Academy).

In the case of the Bamian village in central Bamian, the wind blows primarily from the east over the selected fetch area. Thus, the snow fence must be aligned perpendicular to this flow from a 180- to 360-deg heading. Depending on the topography, deviations of up to 25 deg from the perpendicular are allowable (Tabler 1991). This is particularly helpful in mountainous areas such as Bamian where a uniform wind direction is not constant.

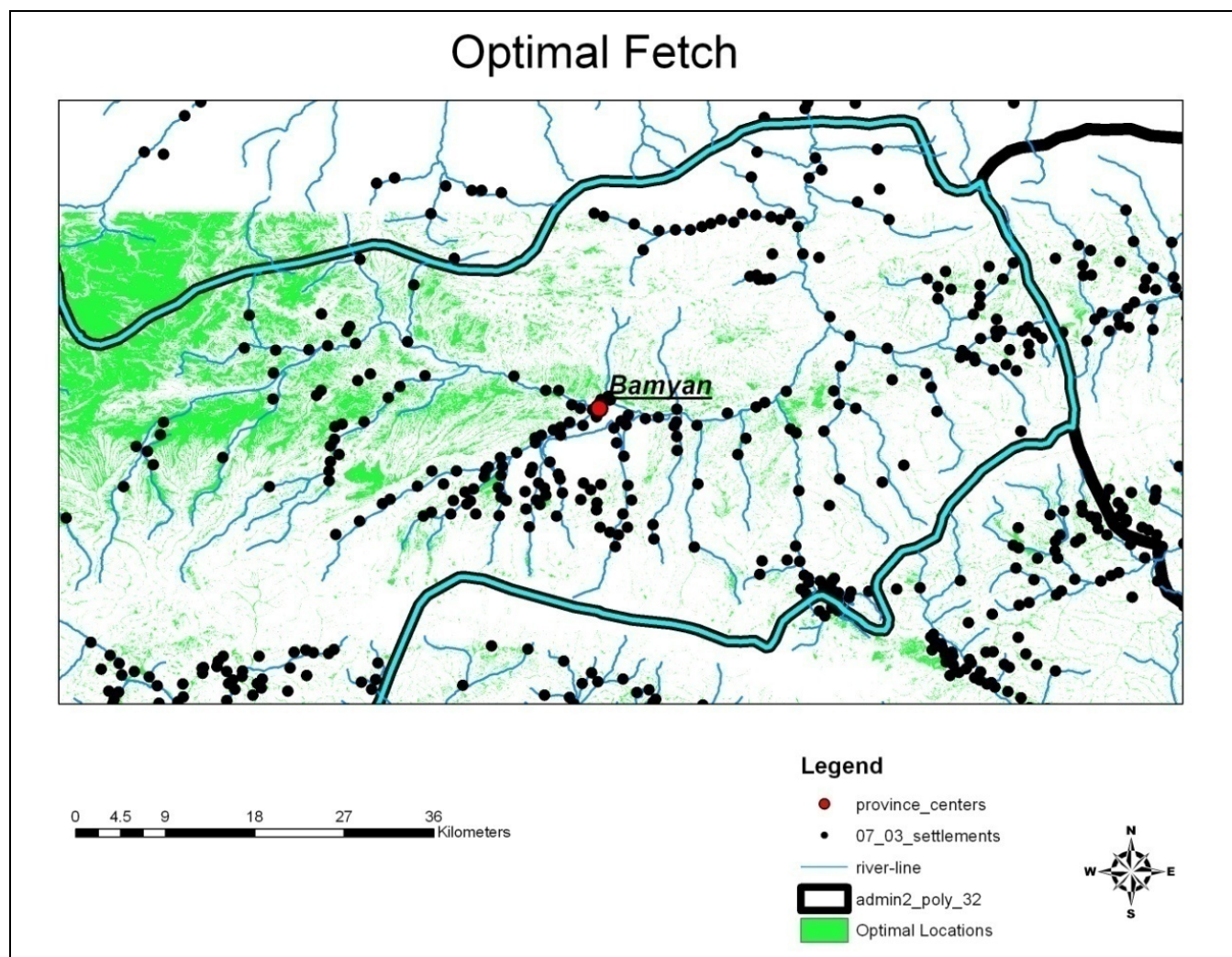


Figure 10. Northeast corner of the Bamian province depicting areas of optimal fetch where both optimal slope and rangeland occur simultaneously (GIS analysis, 2008, Department of Geography and Environmental Engineering, U.S. Military Academy).

Data gathered from a Bamian weather post from 1973 to 1980 show that there is somewhat of a prevailing easterly wind during the winter months (November-March). However, further analysis should be conducted to verify these data, since local wind patterns vary considerably in the mountainous areas (Figure 12).

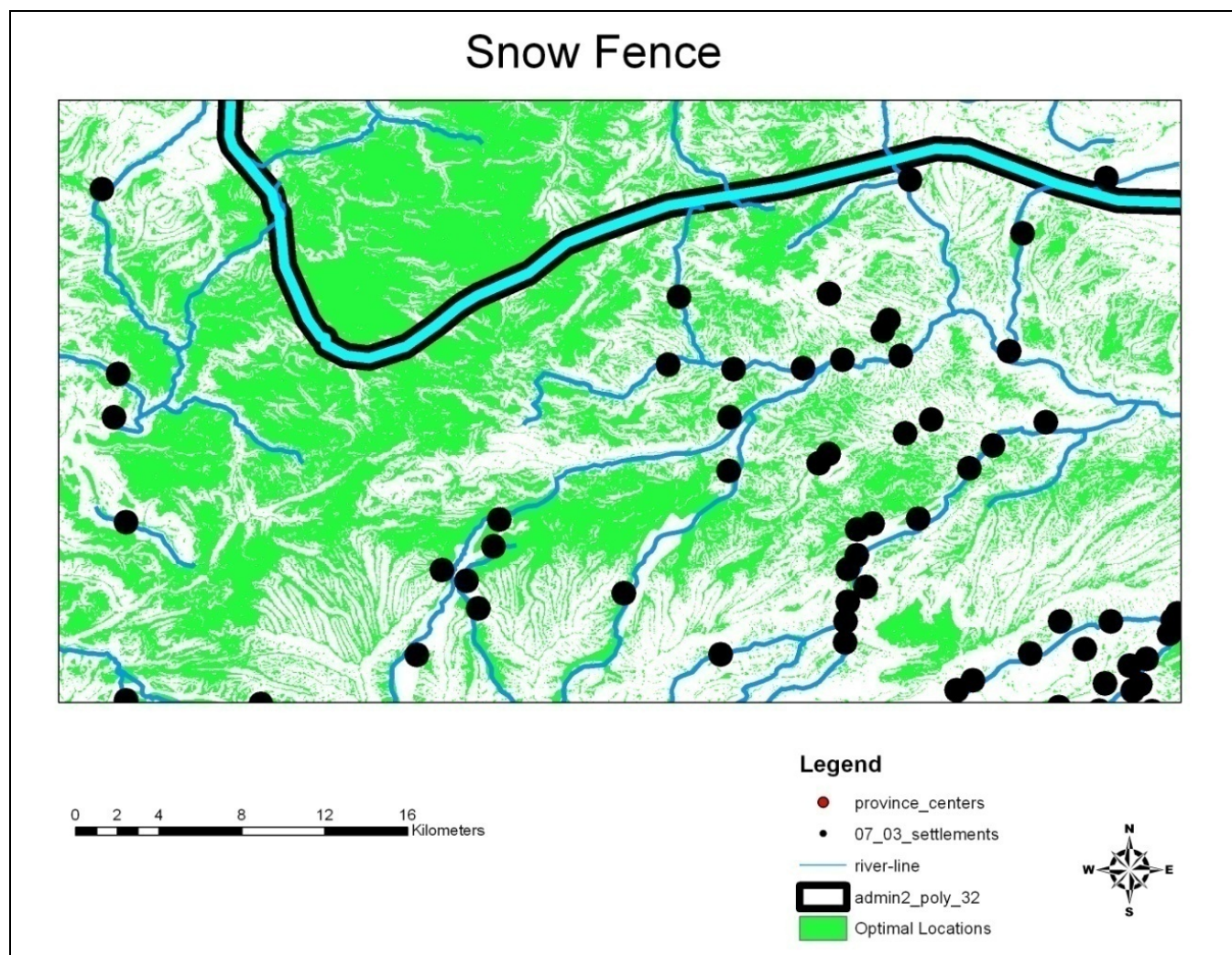


Figure 11. Expanded map of Bamian depicting areas of optimal fetch for snow fence (GIS analysis, 2008, Department of Geography and Environmental Engineering U.S. Military Academy).

If the snow fence water-collection method is implemented for a village, the water could be stored in various ways. For example, a properly sized water storage basin can be excavated, lined, and placed adjacent to and downslope of the snow drift for purposes of capturing snowmelt. If there is an irrigation system, it may be possible to place the snow fence such that melt water feeds into it, or into underground storage that can be accessed later.

Snow fence materials

The analysis performed above is based on several assumptions, including the use of a highly efficient, 50% porous snow fence. However, this may not be practical in Bamian, as we are unfamiliar with the lumber resources in this region and

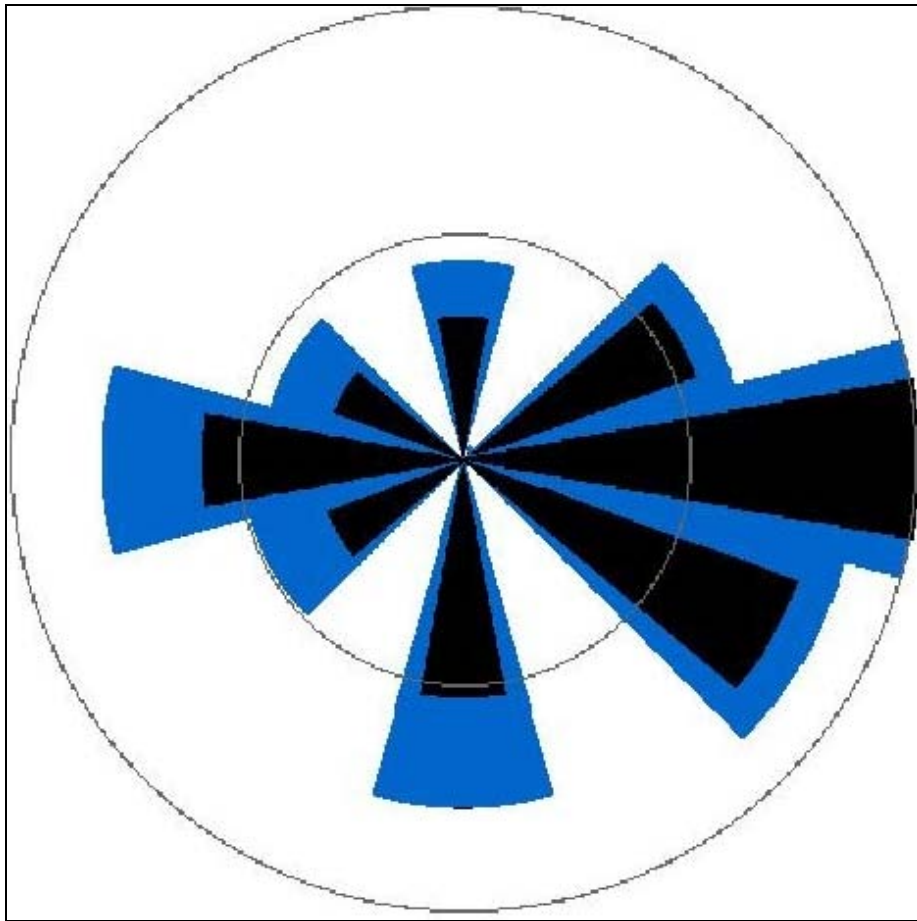


Figure 12. Wind rose diagram of Bamian shows wind coming predominantly from the east. The outer wedge represents the frequency of winds originating from a specified direction. The inner wedge represents the wind frequency multiplied by the wind speed to show each sector's contribution to the average wind speed (Danish Wind Industry Association 2003).

assume the rangeland contains few trees. Further, lumber handily available on a snow fence could easily be removed to provide a source of fuel. If lumber is not a likely material for snow fence construction, rocks certainly would be. According to Tabler, a solid snow fence stores approximately the same amount of snow on both the upwind and downwind sides, and the capacity is approximately 35% that of a porous snow fence.¹ Hence, in this case, a 100-m-wide “solid” fence, approximately 3 m high, would still provide 16%–17% of the annual village livestock water.

¹ R. D. Tabler, pers. commun. 2008. Research Hydraulic Engineer, Tabler & Associates, Niwot, CO.

4 Socioeconomic Considerations

Before introducing a new water source to a village, the socioeconomic implications should be considered. The social hierarchy of Afghan villages largely depends upon who controls the water sources (Klijn 2002). Women and children may gain or lose social status because of a new water source. Those who gather water may have more time to contribute to the family and village because they have more time to learn, work, and make money. Additionally, one must consider how the villages downslope of the stored snow water will be affected. Some downslope villages may be deprived of the much-needed snowmelt. However, these same villages may possibly benefit in that the diverted snowmelt via the snow fence and storage could alleviate springtime flooding, which is a recurring problem in Bamian.

5 Conclusions and Recommendations

Conclusions

Harvesting snow in Bamian, Afghanistan, via the snow fence collection method shows significant promise as a practical supplementary source of water for farm animals or irrigation. Based upon a terrain and climate analysis of an “average” Bamian village consisting of 167 cows and 834 sheep, approximately 16%–47% of the cow and sheep annual water requirements could be met using the snow fence collection method. The 47% represents the 9400 m³ of water expected to be obtained from a 100-m-wide and 3-m-tall 50% porous snow fence, with a 1.5-km fetch, and 0.25-m annual SWE. If rocks were to be used to build a “solid” snow fence, about 16% of the annual water requirements would be met.

These estimates are somewhat conservative based upon the following assumptions: one third of the snow water would be lost to evaporation; another one third to overland conveyance; the maximum transport distance for the snow is 3000 m; and a SWE of 0.25 m in the winter months.

Recommendations

The research team’s recommendation is to further assess implementation of the snow fence water-collection method as a supplementary source in rural areas of Afghanistan that receive annual snowfall. As a part of further study for a specific village, the socioeconomic situation of the village must be thoroughly analyzed. With this considered, snow harvesting in Bamian, Afghanistan, should help alleviate the water shortage problem experienced during exceptionally hot, dry summers and cyclical drought.

References

- Agromet Network. 2007 *The Afghanistan Agrometeorological Monthly Bulletin* 26:1–14.
http://afghanistan.cr.usgs.gov/downloadfile.php?file=0702_afghanistans_agromet_bulletin_for_the_month_of_february_2007_english_version_10-24-08.pdf.
- Alim, A. K., and S. S. Shobair. 2002. Drought and human suffering in Afghanistan. In *TAEAS 2002 Proceedings*, 119–127. Agricultural and Forestry Research Center.
- Canfield, R. L. 1973. The ecology of rural ethnic groups and the spatial dimensions of power. *American Anthropologist* 1513–1519.
- Danish Wind Industry Association. 2003. Wind rose diagram.
<http://www.windpower.org/en/tour/wres/roseplot.htm>.
- Encyclopedia Britannica*. 2008. Afghanistan. <http://www.britannica.com/eb/article-226141/Afghanistan>.
- Gill, I. 2008. Afghanistan: Breathing life into an ailing village.
http://www.adb.org/documents/periodicals/adb_review/2003/vol35_3/breathing_life.asp.
- Illinois Institute of Technology. 2008. Afghanistan country study: The natural environment.
<http://www.gl.iit.edu/govdocs/afghanistan/TheNaturalEnvironment.html>.
- International Center for Agricultural Research in the Dry Area. 2002. Needs assessment on soil and water in Afghanistan. In *Future harvest consortium to rebuild agriculture in Afghanistan*. Aleppo, Syria: U.S. Agency for International Development.
- Jairell, R. L., and R. A. Schmidt. 1992. Harvesting snow when water levels are low. In *60th Western snow conference, Apr 14–16, Jackson, Wyoming*.
- Kelly, A. T. 2003. Rebuilding Afghanistan's agricultural sector.
http://www.adb.org/Documents/Reports/Afghanistan/Agriculture/Rebuilding_Agriculture_Sector_AFG.pdf.
- Klijn, F. 2002. Water supply and water collection patterns in rural Afghanistan—an anthropological study. <http://www.dacaar.org/upload/Source/PDf/executivesummary.pdf>.
- Livelihoods Connect. 2008. Eastern Hazarajat district profiles; FAO Afghanistan Program.
http://www.livelihoods.org/lessons/docs/FAOafgh_AgriProfiles.doc.
- Masood, A., and W. Mahwash. 2008. Water resource development in Northern Afghanistan and its implications for Amu Darya Basin. *World Bank Working Paper No. 6*. http://www-wds.worldbank.org/external/default/WDSPContentServer/WDSP/IB/2004/07/27/000090341_20040727112339/Rendered/PDF/297030PAPER0Water0resource0Amu0Darya.pdf.
- McFadden, T. T., and C. M. Collins. 1978. *Fresh water supply for a village surrounded by salt water, Point Hope, Alaska*. Special Report 78-07. Hanover, NH: Cold Regions Research and Engineering Laboratory.
- New South Wales Department of Water and Energy. 2007. How much water do I need for my rural property? *Water Management in NSW*.
http://naturalresources.nsw.gov.au/water/pdf/farmdams_how_much_water_do_i_need_2.pdf.

- Palka, J. P., ed. 2001. *Afghanistan: a regional geography*. Department of Geography and Environmental Engineering. West Point, NY: U.S. Military Academy.
- Sturges, D. L. 1992. Streamflow and sediment transport responses to snow fencing a rangeland watershed. *Water Resources Research* 28(5):1347–1356.
- Tabler, R. D. 1991. *Snow fence guide*. Washington, DC: Strategic Highway Research Program. 9–24.
- _____. 2003. Controlling blowing and drifting snow with snow fences and road design. 43–46; 106. <http://www.tablerassociates.com/downloads.htm>.
- U.S. Department of Agriculture, Natural Resources Conservation Service. 2008. What is snow water equivalent? <http://www.or.nrcs.usda.gov/snow/about/swe.html>.
- UN-Water. 2007. Coping with water scarcity: Challenge of the twenty-first century. <http://www.unwater.org/wwd07/downloads/documents/escarcity.pdf>.
- Yule, C. B. 1890. Afghanistan. In *Encyclopedia Britannica: a dictionary of arts, sciences, and general literature*, 9th ed. New York: The Henry G. Allen Company.

REPORT DOCUMENTATION PAGE				Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing this collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number. PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.					
1. REPORT DATE (DD-MM-YYYY) August 2009		2. REPORT TYPE Final report		3. DATES COVERED (From - To)	
4. TITLE AND SUBTITLE Snow Harvesting: A Potential Water Source in Afghanistan				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) Kyle J. Thompson, Karen S. Henry, Janet P. Hardy, and Adam M. Chalmers				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Military Academy, Department of Civil and Mechanical Engineering, West Point, NY 10996-1905; U.S. Air Force Academy, Department of Civil and Environmental Engineering, USAF Academy, CO 80840-6232; U.S. Army Engineer Research and Development Center Cold Regions Research and Engineering Laboratory 72 Lyme Road, Hanover, NH 03755-1290				8. PERFORMING ORGANIZATION REPORT NUMBER ERDC/CRREL SR-09-2	
9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES) Headquarters, U.S. Army Corps of Engineers Washington, DC 20314-1000				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT Afghanistan has limited water sources, and the possibility of using a snow fence to concentrate, or "collect," snow to provide a supplemental source of water, upon melting, in the Bamian region was examined. In Afghan villages, women and/or children often fetch water for their families. Improving water usage efficiency could improve agricultural productivity, reduce the number of trips to the nearest water source, and provide healthier daily nutritional intake. Snow fences are currently used to manage the distribution of snow for the purposes of supplementing water supply. Hence, the researchers determined the average amount of water required for sheep and cows per village using demographic data. Then, they compared this volume of water to the equivalent volume of snow that can be captured with a snow fence, based on current knowledge of snow fence function. Analysis of topographic and meteorological data indicated that many areas in Bamian are favorable for collection of snow for eventual water harvesting. A 100-m-wide "solid" fencing (e.g., rocks), approximately 3 m high, was estimated to be able to provide from 16% - 17% of a "typical" Bamian village's livestock water, whereas a highly efficient, 50% porous fence could provide approximately 47% of the livestock water. The research team's recommendation was to further assess implementation of the snow fence water-collection method as a supplementary water source in rural areas of Afghanistan that receive annual snowfall.					
15. SUBJECT TERMS Afghanistan Bamian Province Snow fence Snow water equivalence Water supply					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES 28	19a. NAME OF RESPONSIBLE PERSON
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			19b. TELEPHONE NUMBER (include area code)